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THE PEAK OF THE FLANDRIAN TRANSGRESSION IN VICTORIA, S.E. AUSTRALIA—FAUNAS AND SEA LEVEL CHANGES

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ABSTRACT: The peak of the Flandrian Transgression (ca. 6000 years ago in Australia) has been studied at two sites on the Victorian coast 440 km apart in a direct line. The Warrnambool site in the west is on a stable high where marine Upper Miocene strata are still horizontal, while the Seaspray site in the east is in an area of known earth movements over the same period of time. The sediments at Warrnambool are characterized by calcarenite, and at Seaspray by quartz arenite.

When the sea reached its peak, Warrnambool Bay extended over the Lake Pertobe flats where open bay fossils establish the facies. Two spits of different coloured sands (separate sand systems) enclosed the western end of Warrnambool Bay, and so established a lagoonal system where shell beds were deposited at the peak of the transgression. At Seaspray a similar lagoonal shell bed was emplaced behind a coastal dune.

At Warrnambool the present emergence of the top of the shell bed is 1.76 m. Taking into account compaction and other factors, an emergence of 2 m at the peak of the Flandrian Transgression is estimated. A similar figure was obtained at Seaspray, indicating that for the past 6000 years measurable earth movement has not occurred.

Following a line of latitude the coast of Victoria covers a little over 900 km, but following the coast it is about twice the distance. The peak of the Flandrian Transgression in Australia was about 6000 years B.P. (Gill & Hopley 1971, Thom & Chappell 1975). Around the coast of Victoria the commonest evidence is shell beds of quiet water facies behind coastal dunes and in inlets of various kinds. These shell beds are one of the best categories of evidence for sea level change because (1) they are low energy deposits, (2) the shells were laid below water level, and (3) except near the entrances, lagoons have a water level at or near mean sea level except in flood time. As such shell beds were laid down below water level, and upon draining the fine-grained sediments compacted appreciably (Gill & Lang 1977), the level of the top of the shell bed was usually below mean sea level at the time of deposition.

These shell beds have been studied along the whole coast of Victoria and beyond, but two sites have been chosen for special treatment. At both sites undisturbed cores of the shell beds have been taken, the faunas have been studied, and precise levelling has been carried out. The recently established Australian Height Datum (A.H.D.) (Roelse *et al.* 1971) makes it possible to relate accurately the surveys of the two sites, although 440 km apart in a straight line. One site is at Warrnambool in western Victoria and the other at Seaspray in eastern Victoria (Fig. 1).

WARRNAMBOOL SITE

The remarkable sequence of onlapping calcarenite formations at Warrnambool (Gill 1977 and Fig. 2) in an embayment eroded by a Pliocene river may be a suitable world Quaternary standard section. They onlap a basalt dated at 1.95 million years old. For section with dates see Reeckmann and Gill (1981). The formations of the past 400 000 years have been shown to be couplets of shallow marine to beach deposits overlain by aeolian sediments. Because of the rapid cementing of these highly calcareous formations, they retain their original morphology to a high degree, so that their facies can be demonstrated. Their superposition, plus relative dating with C^{13} and O^{18} isotopes, and chronometric dating with C^{14} and U/Th provide a time framework. Each of these couplets marks the peak of an interglacial transgression, of which the Flandrian Transgression is the latest.

The bedrock is a shelf calcisiltite, the Port Campbell Limestone, which is still horizontal for about 100 km. Also no seaward warping is discernible because the declivity from the Miocene shore near Hamilton to the present coast is of the order of 1.5 m/km. This is a remarkable stability even for mid-plate Australia. The Warrnambool sequence overlies the Warrnambool High, a platform of ancient rocks (Kenley 1976), and so is an ideal place to study the peak of the Flandrian Transgression and consider geoidal changes. By contrast the Seaspray site is in an area of continuing tectonic movement.

Other evidence of a higher level for the peak of the Flandrian Transgression are relict cliffs, emerged shore platforms, channels in Holocene platforms extending up into the coastal scrub, overgrown honeycomb weathering in the lichen and dicotyledon zones, dune building seaward of Holocene cliffs, and penetration by the sea of river tracts not now intruded by it.

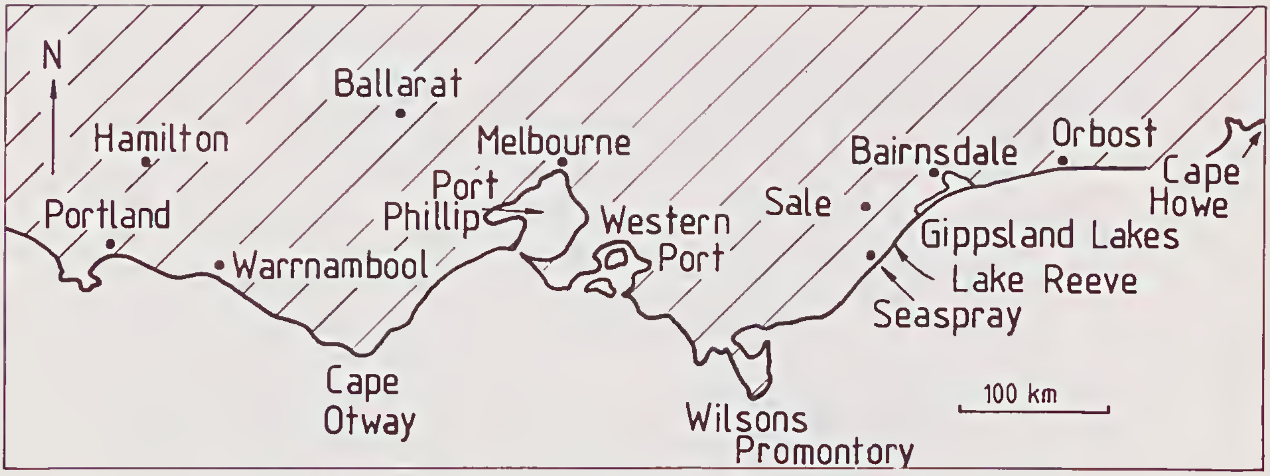


Fig. 1—Map showing localities of Warrnambool and Seaspray, Victoria, Australia.

Lake Pertobe

Three years before the settlement of Warrnambool began, William Pickering reported on the site to Governor La Trobe on 7 December 1844. He described the ample supplies of fresh water, and referred to the "lake which is at present salt, but by throwing a dam across its mouth . . . it could be kept fresh all the year." This is apparently the earliest reference concerning Lake Pertobe, which lies on flats 1-3 m above the sea at the western end of Warrnambool Bay. Following variations in rainfall, it ranges from a body of fresh water to (rarely) a dry lake bed. Under natural conditions it emptied via Pertobe Creek into the Merri River, which debouches at the S.W. corner of Warrnambool Bay (also called Lady Bay). In the Latrobe Library, Melbourne, an unfinished water colour (or draft) made in 1879 is preserved, and Fig. 3 is a pen and ink copy. It shows Lake Pertobe, Pertobe Creek and the Merri River in their natural condition (cf. Fig. 2). The spring tidal range in Warrnambool Bay is 0.9 m.

The Lake Pertobe sediments are sandier to the east, nearer the sand spits that formed the lagoon. The sea entered through a gap between the two termini of the spits 6000 years ago (Fig. 7), and since the sea departed from the lagoon, waves have broken through from time to time. A photograph by Thomas Washbourne taken between 1872 and 1879 (date limits determined by Thomas Wicking from structures in the photo) shows a wide gap with a sandy floor. Such intrusions could not have been frequent or sustained for long, otherwise there would be more sand in Lake Pertobe.

Auger holes have been sunk at a number of places in this area (e.g. see Gill 1953, figs 13, 14), and in 1979 CSIRO drilled a number of bores in the Lake Pertobe flats and the present estuary of the Merri River. Years ago bores were sunk in the Lake Pertobe flats to explore the possibility of building a harbour there, but none of the organizations concerned have been able to produce the logs. In recent years the City of Warrnambool has built an Adventure Park in the area. This involved extensive testing and excavations which have shown the wide extent of the shell bed and the various facies.

Caravan Park Section

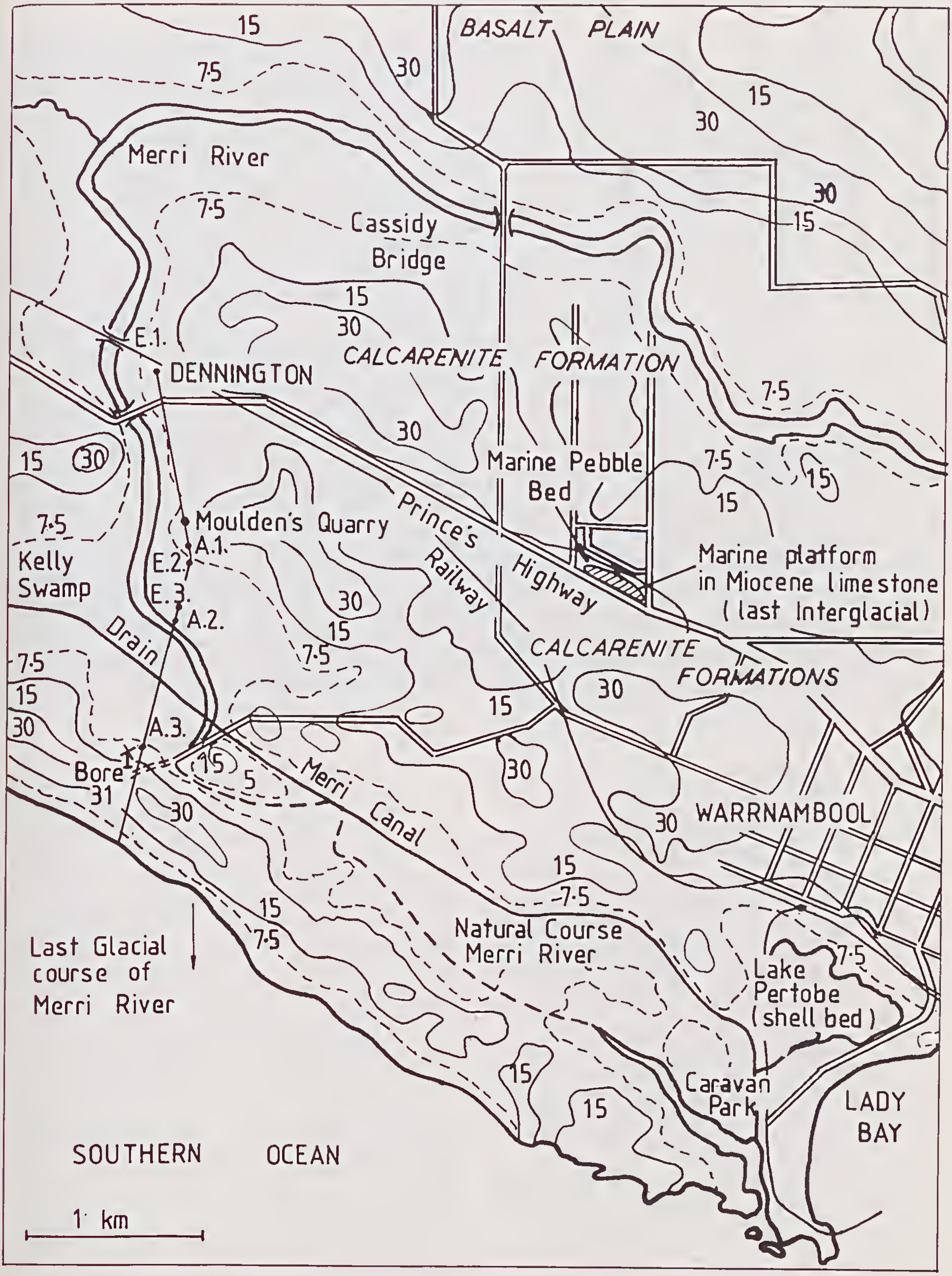
Sewerage trenches dug at the Ocean Beach Caravan Park in Pertobe Road provided an opportunity to study a section in detail and relate it to A.H.D. (Fig. 5). For the general stratigraphy of the area see Gill (1976). The shell bed and its equivalents elsewhere were given the stratigraphic name Pertobe Coquina, following Pettijohn, but now Schreiber (1978) defines a coquinoid as "an autochthonous (in situ) deposit of shelly material, usually having a fine-grained matrix, which may build up, under certain conditions, to biostromes." This description fits the Lake Pertobe deposit very well, so it is re-named Pertobe Coquinoid.

Figure 5 shows the stratigraphic section with a disconformity between the lagoonal coquinoid and the freshwater peat. During the interval, the shell bed was drained (or partly so), and compacted, with some development of secondary carbonate, i.e. an incipient soil formed. The time gap is given approximately by the radiocarbon dates (6570 years for the coquinoid, and 1875 years for the middle and lowest third of the peat). The shells for the C^{14} assay were from 0.27 to 0.37 m above A.H.D. As the area was tectonically stable for the period concerned, the fall in water table to allow the incipient soil to develop infers a fall in sea level. Evidence for this fall is widespread.

Pertobe Coquinoid

Below the Lake Pertobe flats, including the estuary of the Merri River, there is a bed of mostly muddy lagoonal sediments rich in shells, 1-5 m thick, dated 7040 to 5850 years B.P. by radiocarbon (Gill 1971a,

Fig. 2—Locality plan of Warrnambool and Dennington. At Excavation 2 (E.2) is a fossil shore platform with estuarine shells dated 3750 years B.P. The Lake Pertobe shell bed is 6000 years B.P. For description of Dennington section line see Gill 1967a.


BASALT PLAIN
Merri River
Cassidy Bridge
CALCARENITE FORMATION
E.1.
DENNINGTON
Marine Pebble Bed
Moulden's Quarry
A.1.
E.2.
E.3.
A.2.
Kelly Swamp
Drain
Prince's Railway
Highway
Marine platform in Miocene limestone (last Interglacial)
CALCARENITE FORMATIONS
A.3.
Bore 31
Merri Canal
WARRNAMBOOL
Natural Course Merri River
Last Glacial course of Merri River
Lake Pertobe (shell bed)
Caravan Park
LADY BAY
SOUTHERN OCEAN
1 km
15
7·5
30
5

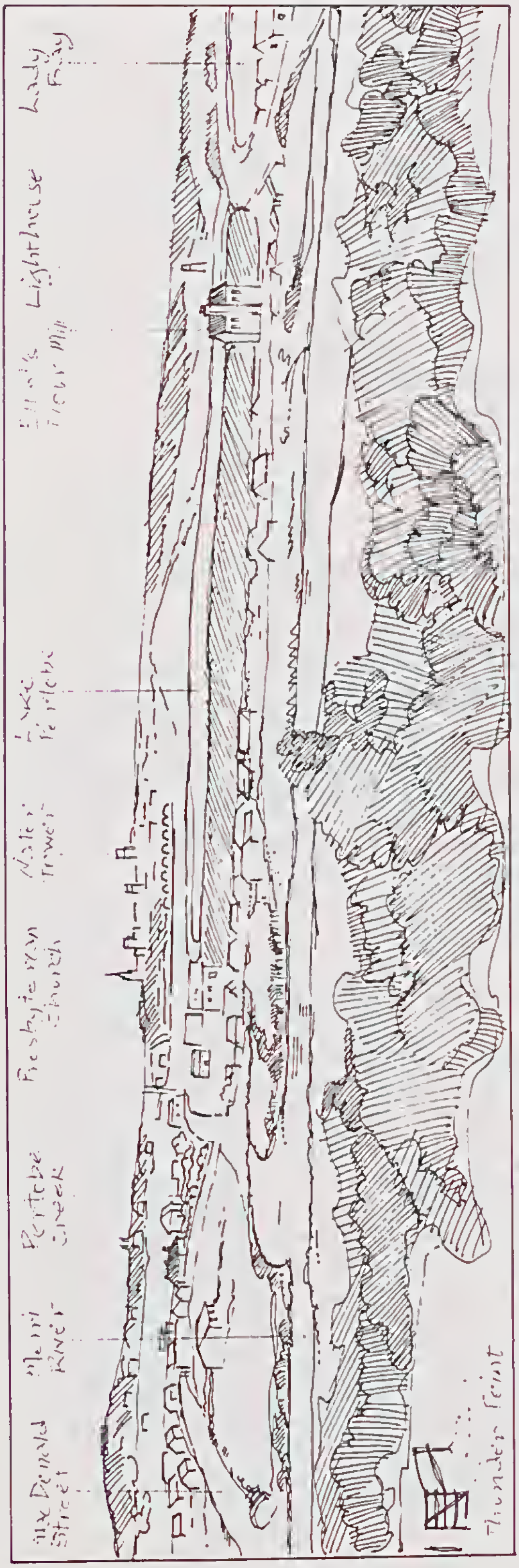


Fig. 3—Line drawing by Don Miller of unfinished water colour made in 1879 showing Lake Pertobe, Pertobe Creek and the Merri River under natural conditions. By courtesy of the Latrobe Gallery, Melbourne.

1973). The base of the shell bed is characterized by open bay shells such as *Katelysia, Ostrea* and *Mytilus*, whereas the major part of the bed is characterized by the lagoonal genera such as *Homalina, Notospisula, Velacumantus, Bembicium,* and *Salinator,* succeeded by fine sandy, muddy and peaty brackish to freshwater sediments as indicated by *Hydrococcus tasmanicus* (tidal saltmarsh), *Coxiella australis* (brackish lake) and *Potomopyrgus niger* (freshwater, usually just above tidal influence). The usual ecological range of these species is given in the Appendix.

Below the shell bed is a layer of fine sand. Although most of the sands in this area are calcarenites, this deposit is entirely siliceous and very well sorted. Its origin is probably in the dry period of about 21 000 to 8500 years ago when a *terra rossa* with calcrete subsoil formed over the calcarenites (Gill 1975). At present, carbonates are not held in the subsoil, but in that dry period a calcrete 0.5-1 m thick accumulated. At the peak of the dry period the A horizon of the *terra rossa* was winnowed away except in the valley floors. Leaching during pedogenesis removed most of the carbonate from the A horizon, leaving essentially quartz and clay. As the bedrock is a consolidated dune sediment, this quartz sand is fine to medium and very well sorted, and the winnowed sand was washed into Warrnambool Bay area while sea level was lower. The sand is grey, except for that on a fossil shore platform under the Pertobe Coquinoid at the foot of Cannon Hill (Gill 1953, fig. 13), where it is red. This red sand was probably washed from Cannon Hill and collected on the platform following a small drop in sea level, and/or because the growth of the spits that created the lagoon lowered the tidal range, although the distance from the entrance of the lagoon is so short that the latter is unlikely.

Tower Hill Tuff

Under the Pertobe Coquinoid at the foot of Cannon Hill is a deposit of Tower Hill Tuff (Gill 1950, 1967a, 1972, 1976, 1978, 1979). Pieces of stratified tuff were noted in the spoil from the dragline excavation of a channel for the Johnson Adventure Park below Cannon Hill. Three characteristics of the tuff are significant:

1. It is stratified with different grain sizes in the various layers, as seen in the airlaid tuff in many places on the Warrnambool terrain.
2. It has the open texture of airlaid tuff, and not the compact texture of waterlaid tuff, as revealed by sewerage trenches in the housing area north of the Princes Highway and east of McGregors Road, East Warrnambool, where fossil water weeds, ripple marks and trails were found.
3. The top of a large piece of tuff brought up by the dragline was oxidized to a yellow colour, suggesting short-term pedological activity. The difference between the C^{14} date for the tuff and that for the oyster bed is 720 years.

In a bore at the foot of Cannon Hill on the Pertobe flats, where the surface is 1.88 m above A.H.D. (virtually mean sea level), the shell bed occupied the top

Fig. 4 – Oblique aerial photograph showing the gap through which, under natural conditions, the sea occasionally broke through. On the right of the gap is the spit of light grey sand, and on the left is the spit of light brown sand (Fig. 7). Photo by courtesy "The Standard", Warrnambool.

2.26 m, including some fill which formed the path where the boring was done. A C^{14} shell sample from 0.3 m below A.H.D. was dated 6250 ± 160 years B.P. Stratified tuff was cored from 2.26-2.87 m, the tuff being mottled red (2.5 YR 8/4) at the base. Below the tuff was red (10 YR 4/6) calcarenite grading to pink (7.5 YR 8/4) and then into normal very pale brown (10 YR 8/3) at 3.77 m, typical of a *terra rossa* soil on calcarenite. If the sea had been present at that time, the soil would have been washed away, and the tuff also, but 7300 years B.P. sea level was lower and the tuff fell on a land surface. Secondary tuff was described over the Pertobe Coquinoid and piled against the Cannon Hill cliff (Gill 1950); it is better to refer to this as tuffaceous colluvium.

On the top of the cliff immediately east of the Thunder Point trigonometrical station is a hollow containing well stratified tuff. East of this is higher ground with traces of tuff on a calcrete surface. Further east is a slope in the lee of the prevailing winds where a layer of unstratified tuff lightly cemented by calcarenite overlies finely laminated mammillary calcite as described from Dennington, the western suburb of Warrnambool and dated 8700 ± 150 years B.P. (GaK-3920) (Gill 1975). At various levels in this unstratified tuff are edible marine shells of moderate size accompanied by charcoal, which are therefore Aboriginal middens. The shells are from two contrasting facies. *Subninella undulata* came from the open ocean rock platforms to the south, while *Mytilus edulis planulatus,* a bay facies shell, must have come from Warrnambool Bay to the north. Sea level was appreciably lower when the Tower Hill Tuff was emplaced, as is shown by the bore at the foot of Cannon Hill cited above, by airlaid stratified tuff at Tower Hill beach extending down below L.W.L., and by similar tuff below L.W.L. under the Kelly Swamp deposits (Fig. 2).

The dune ridge at Thunder Point, on which the tuff deposits lie, is Last Interglacial in age, left stranded as the sea retreated. As the dune bedding extends to about 3 m below present sea level, its age is estimated to be about 95 000 years. Following the return of the sea to its present level, this dune has been cut back just past its centre-line, so that all the dips are landward. The island platforms of this rock left in the sea, and the dips of the dune rock make it possible to reconstruct the dune. Thus, 7300 years ago, the south edge of the dune was about 0.25 km further seaward and, instead of the present islands off Point Pickering, the dune ridge extended

FORMATION & COMPACTION	COLOUR & THICKNESS	LITHOLOGY & FACIES	A.H.D. LEVEL	AGE IN C14 YEARS B.P.
	0.28 m	FILL	Surface + 1.85 m	Modern
Moyne Alluvium 4.8-8.4 kg/cm^2	0.26 m Black	PEAT Freshwater swamp	+ 1.57 m	1875 yr
Pertobe Coquinoid 7.2-10 kg/cm^{2*} some leaching and deposition of secondary carbonate; elongate con- cretions up to 8 cm in long diameter.	1.46 m Light gray 2.5 yr 7/2 with irregular mottles of strong brown 7.5 yr 5/6 Juvenile soil formed on chemically reduced lagoonal deposit before peat formed	At top muddy lagoon with *Homalina* SHELL BED At base open bay facies with *Ostrea* and *Katelysia*	+ 1.31 m H.W.L. springs in open sea A.H.D.	6570 yr on shell sample from + 0.27 to + 0.37 m
At the base of Cannon Hill the Pertobe Coquinoid over- lies subaerially deposited, fine bedded, sur- ficially oxidized TOWER HILL TUFF (7300 yr)		Bottom of excavation 2 m from surface. A nearby excava- tion penetrated to quartz silt.	- 0.15 m L.W.L. springs in open sea	Other dates in same shell bed 6500 yr in Merri Canal near Woollen Mill. Shells about HWM 5850 yr. Shells over fossil shore platform at foot of Cannon Hill

*Penetrometer Readings

Fig. 5—Geological section in Lake Pertobe area at the Ocean Beach Caravan Park, Warrnambool, Western Victoria.

over 1 km east of the present tip of Point Pickering (Figs 6, 7). The middens show that the Aborigines chose a high point for their eating place, yet protected from the cool prevailing S.W. winds. They gathered food from the open coast to the south and from the bay to the north. As the water deepened in the bay, beds of large oysters flourished there, but as yet their shells have not been found in the middens.

Palaeogeography

When the sea first returned from the Last Glacial low level, Warrnambool Bay was more extensive as it occupied also what are now the Lake Pertobe flats, and a shore platform was formed on the north side (Gill 1953, figs 13, 14). It now remains to explain how the Pertobe flats came into existence. Two processes are possible: 1, the prograding of the shore, whereby the land is progressively built seawards; 2, the growth of a sand barrier or spits which cut off the area, after which it gradually infilled with stillwater sediments. A small fall in sea level aids both processes (Gill 1981a), and there is evidence that this occurred. As the muddy Pertobe Coquinoid covers the whole of the area, and is bounded on the seaward side by two opposing spits of different coloured sands, the second process is the one that occurred. A spit of light grey calcarenite grew north from the Pickering promontory (the Merri River was not there then) to near where the Surf Life Saving Club is now (west shore), while from the Last Interglacial calcarenite on the west side of the Hopkins River mouth a spit of light brown calcarenite grew west to near the S.L.S.C. site (north shore). Behind these spits was a lagoon in which the Pertobe Coquinoid was deposited; the sea entered through the gap between them (Fig. 7). When the sea retreated the gap filled, but has always been a weak point. Under natural conditions the sea used to break through there and cross Pertobe Road into the lake. Captain Barrow's original survey of the harbour (1854) shows a submarine sand spit in this area. The aerial photograph (Fig. 4) shows that in spite of foreshore works the gap between the two spit ends can still be readily recognized. From a high point it is easy to see the fine light grey sand of the west shore as distinct from the coarser light brown of the north shore (Fig. 7). The presence of two sand systems has not been previously recognized. At one time it was thought that the source of the sand filling the harbour was to the east, so a seawall was built opposite the Pertobe Cutting in 1919. This was not successful because it was at the end of the light brown sand system; the movement of brown sand finished there and did not continue on into the harbour.

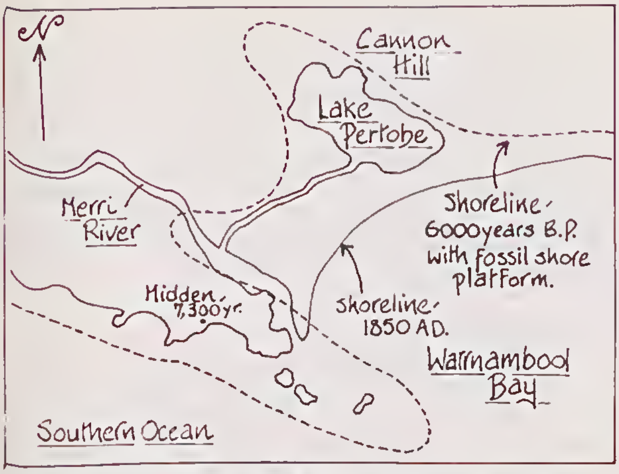


Fig. 6 – Superimposed on map of Lake Pertobe area is the shore line of about 6000 years B.P. (dashed line).

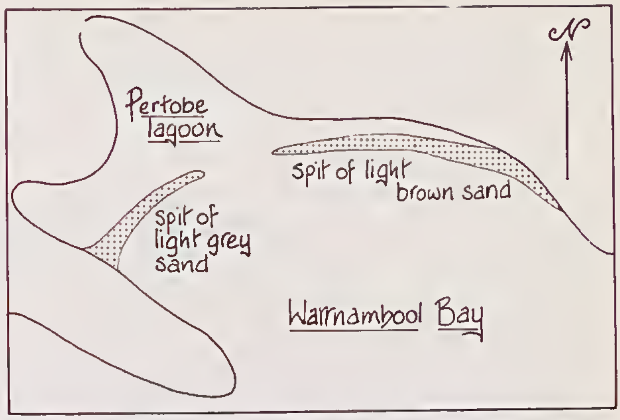


Fig. 7 – The palaeogeography of the Lake Pertobe area, Warrnambool, showing the more extensive Warrnambool Bay at the peak of the Flandrian Transgression about 6000 years B.P., and the two spits that created the lagoon (the area now occupied by the Pertobe flats).

Chronology

Seven radiocarbon dates (uncorrected for seawater age – about 450 years) provide time control for the geological history of the Lake Pertobe flats:

5850 ± 320 (PIC-9) *Homalina*, foot of Cannon Hill, over fossil shore platform.

6250 ± 160 (GX-6788) *Ostrea, Mytilus* and *Notospisula*, bore, foot of Cannon Hill.

6460 ± 110 (SUA-985) *Ostrea*, N. end Lake Pertobe (date recalculated).

6500 ± 200 (PIC-10) *Homalina*, Merri Canal near Warrnambool Woollen Mill.

6570 ± 200 (SUA-780) Fauna with *Mytilus*, Ocean Beach Caravan Park excavation.

7040 ± 205 (GX-6789) Peaty layer (weed bed) with pieces of large shells (including *Katelysia*, open bay genus) plus whole weed shells (cerithiids) under Merri River estuary.

7300 ± 150 (GaK-2856) *Mytilus* and *Subninella* midden in Tower Hill Tuff with calcarenite, E. of Thunder Point.

During the rise of the sea to the peak of the Flandrian Transgression, the two spits that border the Lake Pertobe flats were initiated. As they grew, stillwater areas were created behind them with consequent changes in flora and fauna. The peaty layer dated 7040 years B.P. is the first evidence of this in the excavations. As the spits extended, so the area of lagoon behind them increased. Practically no waves reached this zone, and the tidal currents were weak because of a spring range of only 0.9 m. Shells were moved, but not far, as most are complete and many paired. The shells are so packed in some places that gentle winnowing to remove the mud is suspected. But the large heavy oyster shells provide a biocoenosis, as there was certainly not enough energy to move them. When the buildings at the corner of Pertobe Road and Price Street were constructed, an extensive oyster bed was encountered ("Warrnambool Standard" 17 April 1944). Another oyster bed was recently revealed in excavations at the north end of Lake Pertobe near the railway gates (C^{14} date 6460 years).

Thus in various parts of the Lake Pertobe flats the *Katelysia-Ostrea-Mytilus* open bay facies is dated 7040-6250 years, while the *Homalina-Notospisula-Velacumantus* lagoonal facies is dated 6500-5850 years. This time overlap is to be expected because of the gradual growth of the spits, but the dates do suggest that open bay conditions did not last very long. The spits must soon have extended far enough to establish a stillwater regime with mud deposition (Fig. 7).

The dates so far obtained for the top and bottom of the shell bed give a formation time for the thickest part of 1190 years, but for the greater part of it only 730 years.

Role Of The Merri River

The Merri River flows across the south end of the Pertobe flats, and debouches into Warrnambool Bay. While the Pertobe Coquinoid was being deposited the river did not enter this area, but debouched near Dennington 4 km N.W. of the present mouth. Three bores sunk through the present bed of the river (which is now diverted through the Merri Canal) on the east side of the road to Thunder Point penetrated only Pertobe Coquinoid. There is no proper channel and practically no riverine sediments; the river just floods across the lagoonal shell bed.

During the Last Glacial period the Merri River flowed through the water gap at Dennington and directly south to the sea. The contours on the continental shelf define the valley through which it flowed (Gill 1967a, fig. 15.1). When the sea returned to its present level, the Dennington Spit (Gill 1981b) began to grow to the N.W., forcing the river to flow around it. About 4000 years ago the sea was still reaching the back of what is now Kelly Swamp (Fig. 2), because sea shells overlying an aeolianite shore platform south of Dennington (Gill 1967a, fig. 15.7) were dated at 3980 ± 150 years B.P. (GX-58). That the genus *Homalina* was common indicates that the Dennington Spit had grown far enough to create a sheltered area at the mouth of the river. The Merri River continued to arch round the growing spit until this course became too difficult, and it diverted S.E. along an old interdune swale to Warrnambool Bay. The dating of sediments along this course could determine approximately when the diversion occurred.

Interpretation of Sea Level Stand

Although the top of the shell bed is now emerged, it was below low water when deposited because the shells are mostly low water to subtidal species. The top of the shell bed at the Caravan Park is 1.31 m above A.H.D., which is 1.78 m above low water level. The emergence is thus 1.76 m plus (1) the depth of water above low tide, (2) the compaction due to draining on emergence (probably not very much here), (3) any reduction of the top of the shell bed by erosion as the sea retreated, (4) the lowering of the top of the bed by subaerial weathering following exposure (as shown by secondary carbonate deposition) and (5) leaching by acids following deposition of the peat. To allow 0.24 m for these five factors to round off the emergence at 2 m is a conservative figure. The figure most difficult to quantify is the depth of water over the shell bed. As the distance from the sea into the Lake Pertobe lagoon was so very short, no difference in tidal range from that in Warrnambool Bay is to be expected.

The geology cannot be explained as a function of progradation because of (1) the emergence of the shell bed, and because (2) the western part of the post-Flandrian embayment was cut off by a bay bar, then the enclosed area infilled with muddy sediments, i.e. there was not a gradual migration seaward of the beach ridge due to progradation.

SEASPRAY SITE

The Gippsland Lakes form an extensive body of water behind a siliceous sandy beach and barrier about 7 m high (Bird 1978, Jenkin 1968, Ward 1977). It is a quartz sand system and not a calcarenite system as at Warrnambool. The beach is of open ocean type with high energy waves due to the Southern Ocean swell. A high contrast thus exists between the quiet waters of the lakes system and the surf of the open beach; the differences are clear in both the sediments and the biota. It is thus easy to distinguish which Quaternary beds were

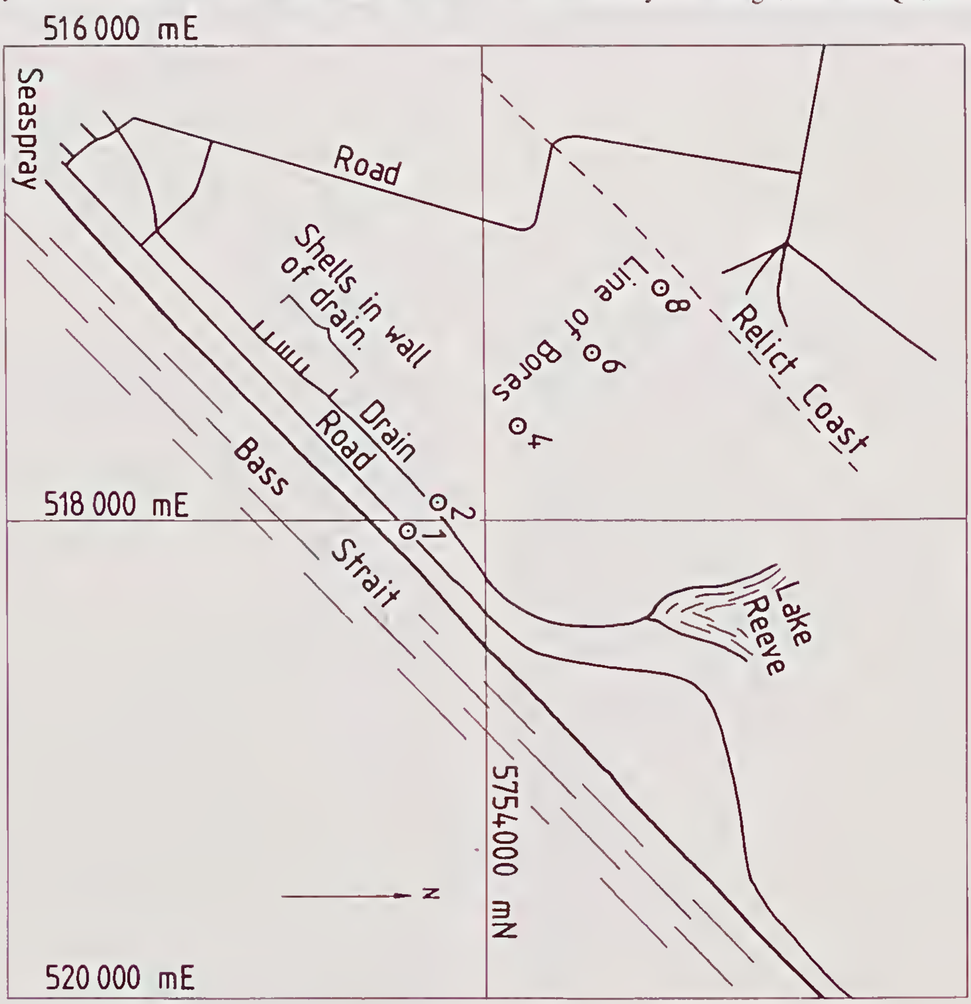


Fig. 8—Map of drain and bore sites between Seaspray and Lake Reeve.

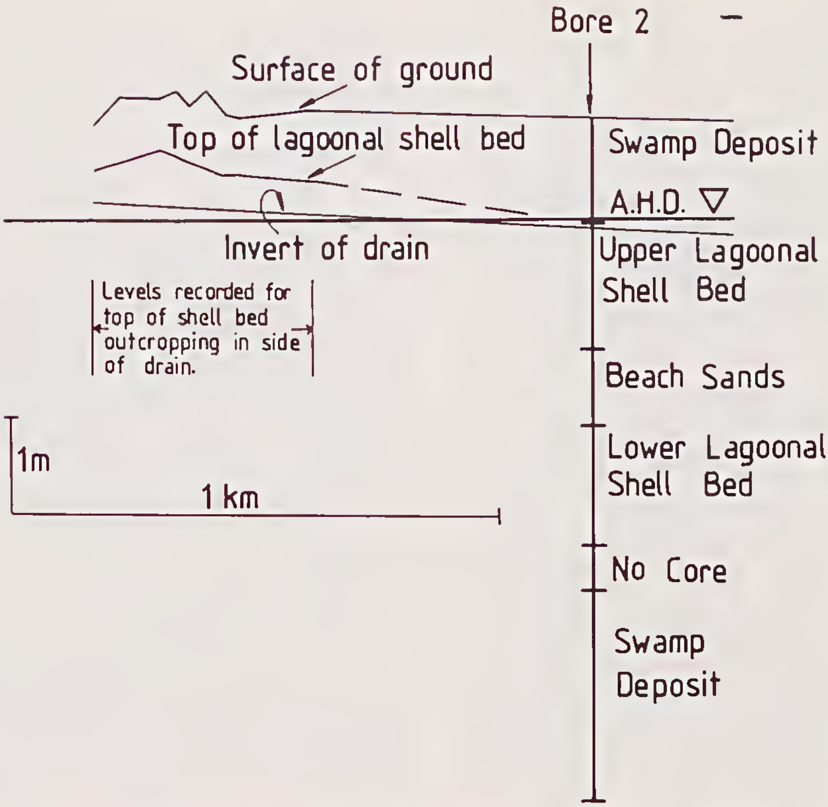


Fig. 9—Longitudinal section along drain from Seaspray to Lake Reeve as shown in Fig. 8.

deposited inside the barrier and which outside (Figs. 8-10).

At the peak of the Flandrian Transgression about 6000 years B.P. the lakes system was far more extensive than now, reaching some 30 km further southwest. The village of Seaspray stands on the lagoonal deposits of this more extensive system, and on a riverine terrace of Merriman's Creek. In 1962 a drain some 3 km long was excavated from Seaspray to Lake Reeve, which is the S.W. end of the present lake system. Under natural conditions the delta of Scott Creek prevented this drainage. This drain provided an excellent section through the emerged shell beds, which were studied and dated by radiocarbon (Gill 1966, 1970, 1971a, b). The CSIRO Division of Applied Geomechanics drilled a series of bores (with undisturbed cores at critical places) normal to the coast across this shell bed in the vicinity of Scott Creek, where the mid-Holocene shore is 1.7 km inland from the present shore (Fig. 8). The delta of Scott Creek provided the only access across the swamp for the drill rig.

Since this work was done, A.H.D. permanent bench marks have been established, and these have been used to determine the height of the shell bed surface in the area. All the pegs put in during our original survey of points of geological interest have now gone. Fortunately our survey was tied into the engineering survey made by the Shire of Rosedale for the engineering works, and it is now possible to relate the local arbitrary engineering datum to A.H.D., and hence also the geological sites (Figs 8, 9).

On the transect the original pegs have also gone, but it has been possible to relate the bore sites to A.H.D. through the level of the road. From photographs of the drilling rig when in position at the site of Bore 1 it has been possible to fix within 1 m the point where the transect crossed the centre of the bitumen road. Another layer of bitumen (without screenings) has been added since the survey, but considering the wear of the road and the thickness of the bitumen, the pavement level can be only 1 or 2 mm different, and this can be ignored. The survey from a permanent survey mark to the transect (0.6 km) and back closed within 1mm, and the level of the centre of the road was determined as 1.773 m A.H.D.

Figure 10 shows a cross-section along the transect, and indicates the relationship of the shell bed to A.H.D. The shell bed is lower along the transect across the flats than it is in the drain behind the dune (Fig. 9). Scott Creek crosses this area and the bed has evidently suffered erosion following fall in sea level. Note that bore sites 3, 5 and 7 of the eight pegged out were not drilled. Fig. 9 shows the levels obtained for the top of the shell bed along the drain parallel to the coast, and along the transect normal to the coast.

Interpretation of Sea Level Stand

It should be noted that the top of the shell bed was surveyed and not the top of the marine bed. At the Lake Pertobe Caravan Park site there is a sharp break between the shell bed and the overlying freshwater peat, but at Seaspray the shell bed is followed by a gradual transition from lagoonal to terrestrial deposits, as also occurs over most of the Lake Pertobe flats. To define the top of the marine bed would require a great deal of micro-palaeontological work. Mr. A. C. Collins determined *Ammonia* and *Trochammina inflata* from this zone; they are estuarine foraminifera. So it is important to observe that the figures for the top of the shell bed are all minimal figures for the height of the marine deposits.

Lake Reeve has a tidal range of only about 15 cm and is virtually at mean sea level. As the water in the drain flows freely down to A.H.D. (M.S.L.) at Lake Reeve, and the shell bed was visible in the side of the drain, and the spoil was crowded with shells, the top of the shell bed there was well above A.H.D. (Fig. 9). This has now been confirmed and quantified by the detailed survey. As most of the species of molluscs lived at low water or below, the shell bed is emerged. As it is a quiet water regime, waves could not lift a whole shell bed above the level at which it was deposited. The fauna indicates that the sea had free access to the area, the spring tidal range is 2.4 m, and the top of the shell bed in the drain is 0.58 m A.H.D. The amount of emergence must therefore be of similar order to that at Warrnambool, where it is given as 2 m. The shell bed was not a result of progradation. During the Holocene the barrier has migrated to and fro a short distance (Gill 1967b), but otherwise there is a bed over 1 km wide of homogeneous coquinoid built up in quiet water behind a coastal barrier.

COMPARISON OF SHELL BEDS 440 km APART

Around the Victorian coast there are numerous similar unoxidized mid-Holocene shell beds which are slightly emerged. Their correlation is clear. However, the precise surveys of two distant sites in contrasting tectonic environments provided an opportunity for comparison. For a long distance through the Port Fairy and Warrnambool districts of S.W. Victoria the Last Interglacial 7 m shoreline can be shown to be without displacement, and the mid-Holocene beds are undisturbed. Although Seaspray in Eastern Victoria is in an area of tectonic movements, no displacement of the mid-Holocene shell bed could be detected, which suggests that the coast there has been stable for the past 6000 years.

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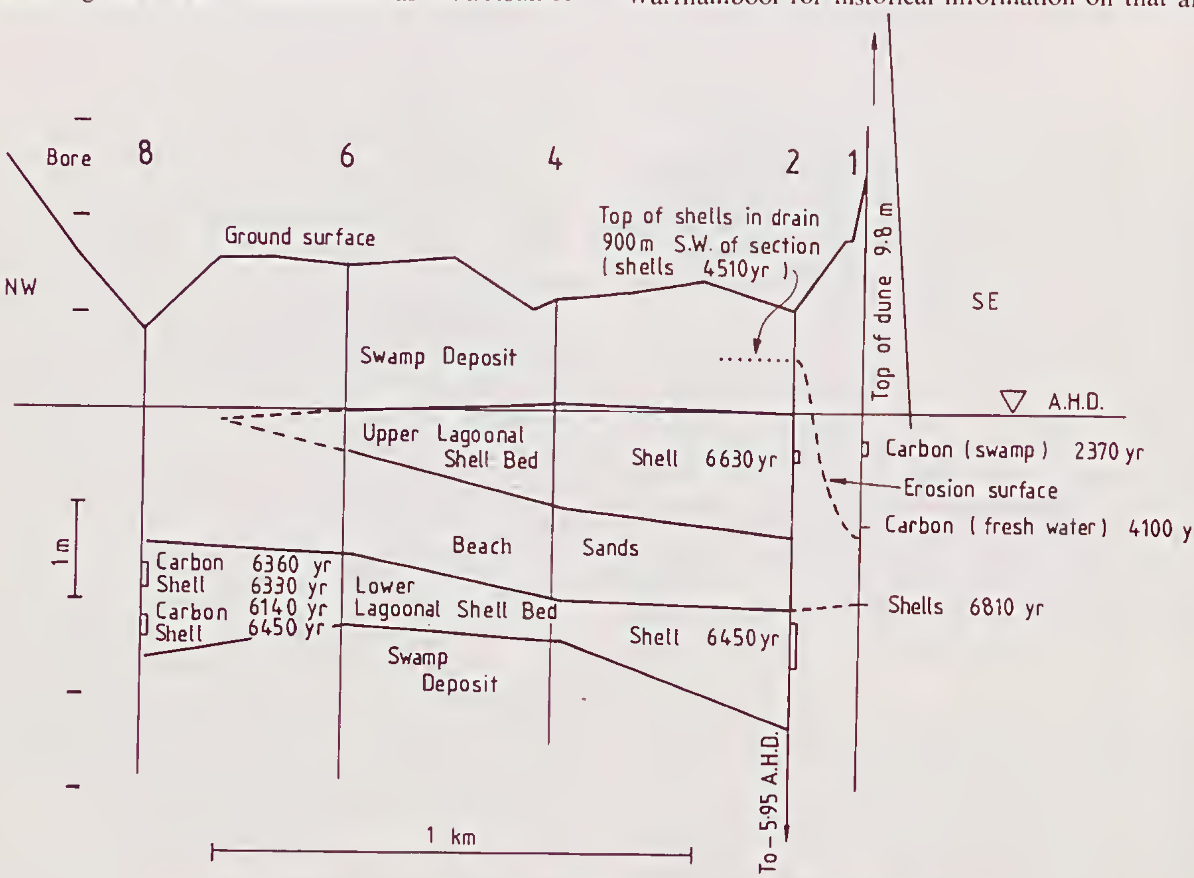

Fig. 10—Cross section from relict coast to present shore, N.E. of Seaspray as shown in Fig. 8.

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APPENDIX

The Fossil Mollusca

By S. E. Boyd

Austrocochlea constricta (Lamarck 1822) — usually found on intertidal rock platforms, but the species has a wide tolerance of habitat and salinity.

Bembicium auratum (Quoy & Gaimard 1834) — quieter waters of sheltered muddy inlets and estuaries, in the upper littoral zone.

Velacumantus australis (Quoy & Gaimard 1834) — found in the shallow waters of estuaries, mangrove swamps and mud flats.

Coxiella striata (Reeve 1842) — brackish water lakes usually away from direct marine influence.

Potomopyrgus niger (Quoy & Gaimard 1838) — freshwater streams, usually just above the region of tidal influence in coastal streams.

Hydrococcus tasmanicus (Tenison-Woods 1876) — on mud between plant roots in tidal saltmarsh areas in sheltered bays and inlets.

Parcanassa burchardi (Philippi 1851) — found on intertidal mud flats.

Salinator fragilis (Lamarck 1822) — mid to upper littoral zone in sheltered marine inlets, on mud and seagrass flats.

Mytilus edulis planulatus (Lamarck 1819) — in sheltered waters attached to rocks and jetty piles. Able to take advantage of very small areas of shelter.

Ostrea angasi Sowerby 1871 = *O. sinuata* Cotton & Godfrey 1938 (non Lamarck) — usually found in estuaries, but marine beds are also found. In Port Phillip Bay it occurs in areas of silty sand and silty clay from low water to approximately 11 fathoms.

Notospisula trigonella (Lamarck 1818) — a very tolerant species occurring in the sands and sandy muds of the shallows of sheltered bays and estuaries.

Homalina deltoidalis (Lamarck 1818) — estuaries, in the mud and muddy sand of the middle to lower littoral zone.

Eumarcia fumigata (Sowerby 1853) — found in shallow water in sand and sandy mud.

Venerupis crenata Lamarck 1818 — in holes and crevices of rocks.

Katelysia rhytiphora Lamy 1937 — intertidal and subtidal in sand and sandy mud, in areas of *Zostera*, etc.

Soletellina biradiata (Wood 1815) — found buried in silty mud in shallow water.